# Classification of Highway Curve Patterns and Its Use for More Accurate Crash Predictions


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**Abstract:** This paper presents an improved crash prediction method that classifies highway curves into several patterns including tangent, single curve, compound curve, and reverse curve. This classification presupposes that a crash is likely to occur being influenced not only by the curve itself but also by the curve surrounding conditions, and this view was tested by applying freeway crash data collected in South Korea to the regression analysis. As a result, it was found that: (1) longer than 2.4km tangent sections were unsafe, (2) single curve sections should be designed with longer radii and lengths to reduce crashes, (3) compound curve section and reverse curve section involved reduced crashes when two consecutive curves have little curve radius change, and (4) fewer crashes were observed when vertical grade values were small. It is believed that this research approach was very effective in explaining crash occurrences for selected freeways, and its wider use is recommended for more accurate crash predictions.



***Key Words:*** *Highway Curve Patterns, Crash Model, Continuous Analysis, Regression Model, Highway Consistency*


## 1. INTRODUCTION

### 1.1 Background and Scope

Motor vehicle accidents continue to be a leading cause of death and injury, and extensive effort has been made by many researchers to explain traffic accident occurrence and factors affecting accidents. The researchers developed various types of model to characterize each crash and made use of their expertise obtained in the model development to accurately predict future accidents. Their predictions can be excellent, but often are poor. How does this

happen? Actually, it is safe to say that no one can predict with great certainty the exact locations and types for all crashes. Nonetheless, the researchers believe that their crash predictions can be improved significantly by applying better analytical skill. For example, Lee and Mannering (1999) stated that applying traffic volume as the exposure in crash analysis might involve prediction error. According to Lee and Mannering (1999), there exists a U-shaped correlation between traffic volume and crash probability. Thus, by modeler's right treatment of traffic volume in the exposure variable, their predictions can be greatly improved. Another example was presented by Jovanis and Chang (1986). They discovered that as vehicle kilometer travelled increases, so does the variance of the accident frequency. Also they found that linear regression is not restrained from predicting negative accident frequency. Apart from these literature review findings, the authors found during our accident modeling process that engineers seemed to make mistakes in determining the highway length subject to analysis. Let us consider Figure 1 that is a conceptual diagram of a highway segment where an accident occurs. Usually engineers determine accident rate based on Area 'A' highlighted in Figure 1. However this length application is wrong because accidents occur being influenced not only by isolated highway geometrics in the accident site but also by continuous highway geometrics that include the upstream segment. This problem must be resolved to get reliable crash predictions, and this research attempts to characterize how surrounding areas for a crash site influence the development of the accident model. A more engineering oriented crash prediction method assuming that a crash is likely to occur being influenced by both the curve itself and the surrounding continuous curve geometric conditions is adopted in this research.

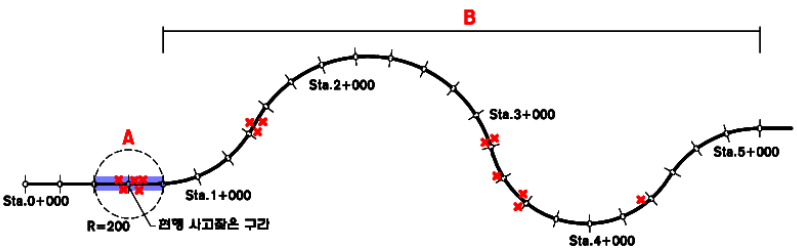


Figure 1 Isolated Analysis of Highway Curves

### 1.2 Research Approach

This research uses the following approach. First, considering the effects on crash occurrences of different highway curve settings, the research classifies horizontal curve patterns into a few distinctive types. Second, crash data and the as-built plan and profile drawings are integrated into a single data base. Third, statistical analysis is done to investigate the relationships between different highway curve settings and crash occurrences.

## 2. CONTINUOUS HIGHWAY SEGMENT AND ANALYSIS

This research underscores the importance of applying the consistency concept in geometric design, and for the most part tries to apply it to develop more accurate highway curve crash models. The essence of the consistency concept in geometric design is to avoid abrupt speed changes in operating speeds, and the consistency concept became an important design issue since 1960s (2). In this research, it is hypothesized that this speed change would also have

substantial impacts on crashes, and the speed change would be in return influenced by the upstream and downstream geometric conditions of a curve. Therefore, instead of applying the isolated geometrics of a curve, the continuous highway geometric condition as presented in Figure 2 is applied in this research to develop more reasonable and accurate crash models.

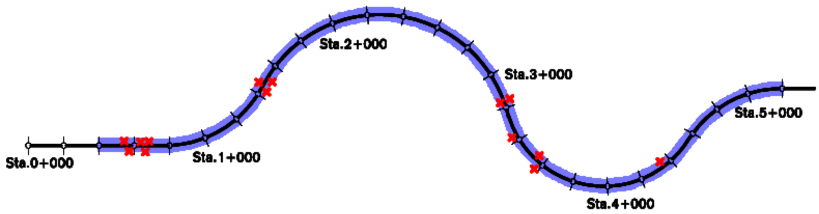


Figure 2 Continuous Analysis of Highway Curves

## 3. DATA BASE DEVELOPMENT

The data base for this research for the most part consists of 9 four lane freeway segments in South Korea. Total length is 1,399.8 km, and geometric conditions and crash characteristic data are provided by the Korea Highway Corporation and integrated into a primary data base for this research. Table 1 summarizes the list of freeways involved in this research.

Table 1 Freeway List for this Research

| No. | Freeway Name | Opening Date | Segment | Length(km) |
|---|---|---|---|---|
| 10 | Namhae Freeway | 1973.11.14 | Soonchun ~ Masan | 127.1 |
| 15 | WestSea Freeway | 2001.12.21 | Mokpo ~ Seocheon | 160.9 |
| 20 | Iksan-Pohang Freeway | 2004.12.8 | Dodong JCT ~ Pohang IC | 68.4 |
| 25 | Honam Freeway | 1973.11.14 | Soonchun ~ Nonsan | 194.2 |
| 35 | Daejon-Jinju Freeway | 2001.11.29 | Jinju ~ Biryong | 215.3 |
| 45 | Jungbu Inner-side Freeway | 2004.12.15 | Masan ~ Yeoju | 203.6 |
| 50 | Yeongdong Freeway | 1975.10.14 | Saemal ~ Gangneung | 91.5 |
| 55 | Central Freeway | 2001.12.19 | Geumho ~ Chuncheon | 278.6 |
| 65 | Donghae Freeway | 1975.10.14 | Donghae ~ Gangneung | 60.2 |

The KHC provided the freeway geometric condition in CAD form for this research. However, the provided data were in fragmented forms, and this research has to combine them with surrounding geometric condition so as to get the continuous characteristics of highway curves and their associated crash patterns. The followings are the highway geometric elements extracted for this research.

- Tangent: length
- Curve: radius, length
- Transition Curve: clothoid parameter (A), length
- Vertical: grade (upgrade, downgrade)

This research acquired initial crash data from the KHC for three years 2003-2005, but this data was intended to be applied for the isolated analysis of highway curve shown in Figure 1. Therefore, an additional effort was needed to match them to the continuous analysis of highway curve. This required lots of laboratory work, because it was needed to extract 2,540 highway geometry related crashes out of the total of 9,707. Then a schematic arrangement for linking the tangent and curve characteristics to freeway crash occurrences was made in this research. Table 2 and Table 3 summarize the result.

Table 2 Linking Highway Geometric Conditions to Crash Occurrences (Tangent Section)

| Tangent Length | No. of Section | Ave. Length(m) | AADT(veh/day) | Ave. Accident Rate (100mil.veh.km) |
|---|---|---|---|---|
| 0~500 | 658 | 247 | 31,018 | 5.60 |
| 500~1000 | 395 | 730 | 29,763 | 4.77 |
| 1000~1500 | 167 | 1,240 | 25,893 | 3.92 |
| 1500~2000 | 82 | 1,734 | 28,646 | 3.95 |
| 2000~2500 | 52 | 2,264 | 18,370 | 2.54 |
| 2500~3000 | 26 | 2,747 | 21,388 | 3.67 |
| 3000~3500 | 14 | 3,170 | 17,854 | 4.18 |
| 3500~4000 | 6 | 3,756 | 20,689 | 5.70 |
| 4000이상 | 4 | 4,569 | 19,689 | 7.81 |

Table 3 Linking Highway Geometric Conditions to Crash Occurrences (Curve Section)

| Tangent Length | No. of Section | Ave. Length(m) | AADT(veh/day) | Ave. Accident Rate (100mil.veh.km) |
|---|---|---|---|---|
| 0~500 | 80 | 463 | 38,832 | 9.56 |
| 500~1000 | 450 | 673 | 32,457 | 5.01 |
| 1000~1500 | 359 | 833 | 29,429 | 4.31 |
| 1500~2000 | 129 | 1,101 | 28,942 | 3.28 |
| 2000~2500 | 204 | 973 | 28,618 | 3.73 |
| 2500~3000 | 55 | 1,102 | 22,698 | 7.16 |
| 3000~3500 | 154 | 847 | 22,101 | 3.78 |
| 3500~4000 | 30 | 992 | 21,516 | 6.97 |
| 4000이상 | 175 | 778 | 21,819 | 4.07 |

## 4. DEVELOPMENT OF MODELS

### 4.1 Classification of Highway Geometric Conditions

In crash analysis, it is important to apply an appropriate amount of highway unit length. This length separates one highway length from others, and if too short a length is applied, the effect of surrounding highway conditions might be excluded, and if too long, the detailed local crash site effect can be excluded. In this regard, this research decided to use approximately 300 meters as the unit highway length, based on 120 km/h design speed, pre-maneuver time 4 seconds, and driver deceleration 3.4 m/sec/sec. Another important highway length criterion applied in this research was the a priori highway length that is the upstream highway length from a crash site where the motorist travels and approaches to the crash site, resulting in varying degrees of crash severity or crash patterns depending upon how motorists absorb the geometric characteristics associated with the upstream highway segment. In order to fully capture the essence of the consistency concept discussed in section 2, this priori highway length determination must be made very carefully in this research, and as a result,

2.4 m length was selected. This value usually covers 2 or 3 highway curves and tangent sections. Figure 3 presents how this research classifies the highway curve types.

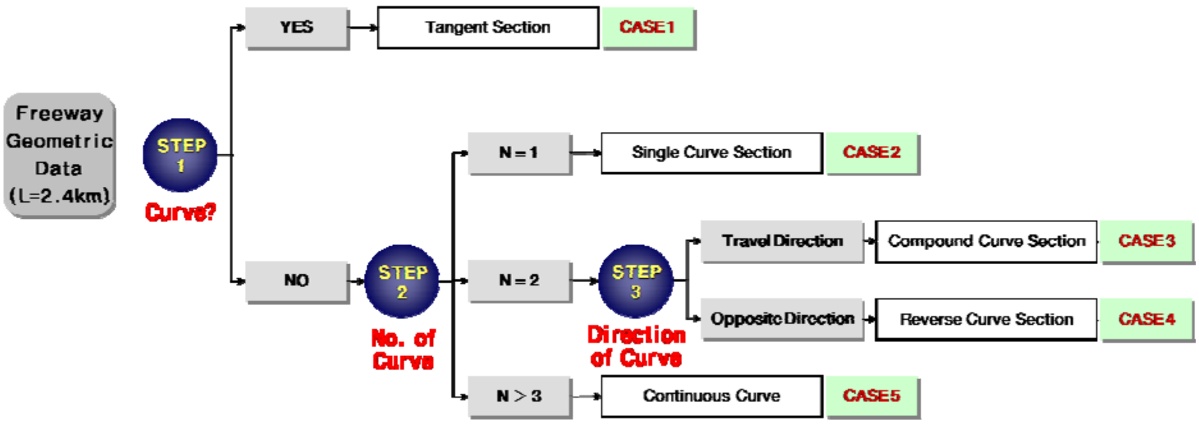


Figure 3 Classification of Highway Curve Types used in this Research

It is to be noted that few cases were observed for CASE 5, so this research precluded it in further analysis. Figure 4 illustrates the four cases of the highway curve type classification.

- CASE 1: Tangent Section
- CASE 2: Single Curve Section
- CASE 3: Compound Curve Section
- CASE 4: Reverse Curve Section

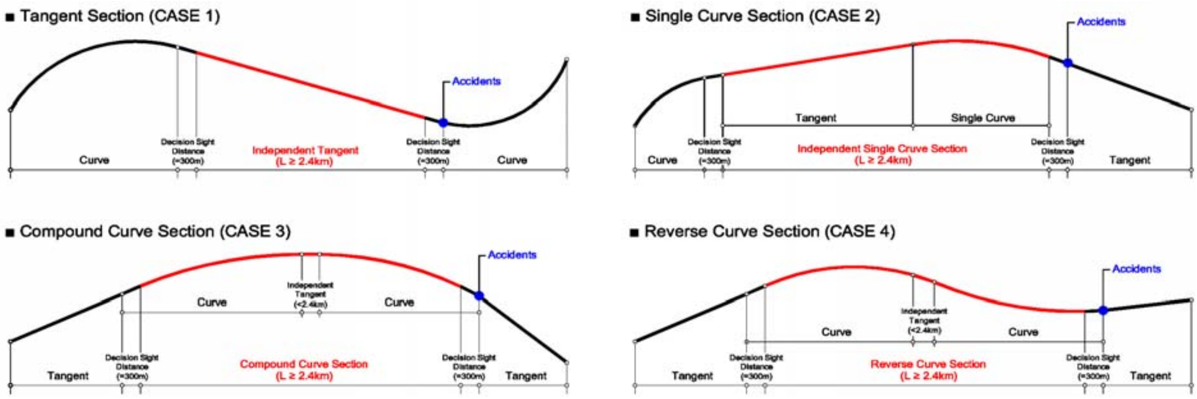


Figure 4 Four Cases of the Highway Curve Types

### 4.2 Regression Model

The multi-regression analysis was applied in this research to develop relationships between accident rate and highway geometric characteristics. This analysis assumes that dependent variables and independent variables are linearly related, and that dependent variables have equal variance regardless of the magnitudes of independent variables. However, it is accepted in crash model development that the variance exceeds the mean values. Therefore, variable transformation was required in this research. Eqn (1) is the regression model applied in this research.

$$Y = \beta_{0'} + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \varepsilon \qquad (1)$$

| Variable Transformation Formula | Regression Model |
|---|---|
| Logarithm Model | $Y = \beta_{0'} + \beta_1 \log(x_1) + \cdots + \varepsilon$ |
| Inverse Model | $Y = \beta_{0'} + \frac{\beta_1}{x_1} + \cdots + \varepsilon$ |
| ⋮ | ⋮ |

Where, $Y$ : Dependant Variable

$X$ : Independent Variables

$\beta_1 \sim \beta_n$ : Coefficients

$\varepsilon$ : Error

### 4.3 Independent Variables

Table 4 shows the independent variables selected in this research that were expected to be able to explain the highway geometric characteristics influencing crashes on the road. Putting these independent variables into the four cases of highway curve types established previously, this research finally set a set of regression equations.

Table 4 Independent Variables used in this Research

| | Tangent Section | Curve Section |
|---|---|---|
| Dependant Variable | Accident Rate(100mil.veh.km) | |
| Independent Variable | Tangent Length(m),<br>Vertical Grade Value | Radius(m), Curve Length(m)<br>Vertical Grade Value |
| dummy Variable | Clothoid | |

### 4.4 Others

In the independent variable selection process, there were two things to mention. First, clothoid curves were also included in this analysis as dummy variable due to their contributions in providing drivers with better curve driving conditions. Second, in spite of apparent impact of the vertical grade on crash occurrences, it is challenging to include individual vertical grade values in the crash model development because these values usually keep changing on the road. Therefore, this research applied the average grade technique instead. Figure 5 and Eqn (2) present how this research treated the vertical grade.

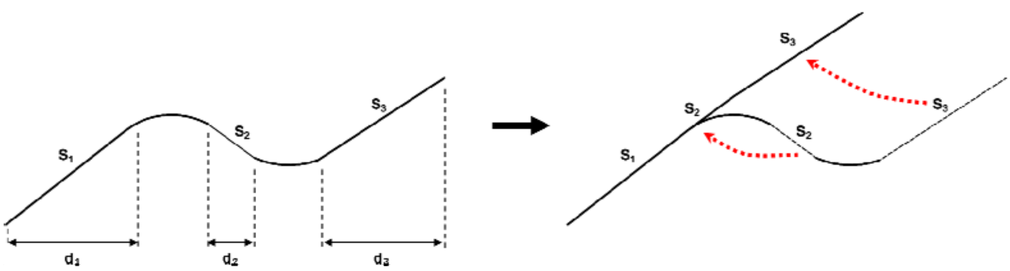


Figure 5 Average Vertical Grade Values used in this Research

$$Vertical\ \ Grade\ \ Value = \sum_{k=1}^{n} \left| \frac{S_k}{100} \times d_k \right| \qquad (2)$$

## 4.5 Developed Models

Table 5 summarizes the developed models in this research. Based on these models, the followings can be stated:

- Longer than 2.4km tangent sections were found to be unsafe.
- Single curve Sections should be designed with longer radii and longer lengths to reduce crashes.
- Compound curve section and reverse curve section involved reduced crashes when two consecutive curves have little curve radius changes, and also showed crash reductions with longer tangent sections between them.
- Fewer crashes were observed when vertical grade values were small, and particularly so if the changes from adjacent sections were minimal.

Table 5 Developed Models in this Research

| | Developed Models |
|---|---|
| CASE 1 | $Y = 23.76\ln(L - DS \times A_1) + 1.57 Bend_{Ver.}$ |
| CASE 2 | $Y = \frac{3,127.612}{R} - 0.047\ln(CL - DS(A_1 + A_2)) - 0.02\ln(L) + 0.60 Bend_{Ver.}$ |
| CASE 3 | $Y = 0.003\lvert RR\rvert + 0.003\ln(CL - DS(A_1 + A_2)) - 0.03\ln(L) + 2.74 Bend_{Ver.}$ |
| CASE 4 | $Y = 0.001\lvert RR\rvert + 0.001\ln(CL - DS(A_1 + A_2)) - 0.03\ln(L) + 2.37 Bend_{Ver.}$ |

Where, $Y$ : Accident Rate(100mil.veh.km)

$L$ : Tangent Length (m)

$R$ : Radius (m)

$CL$ : Curve Length (m)

$DS$ : Decision Sight Distance (=300m)

$Bend_{Ver.}$ : Average Vertical Grades

$A_1$ : Dummy Variable

(0 : Existence of Clothoid in Beginning of Curve

1 : No Existence of Clothoid in Beginning of Curve)

$A_2$ : Dummy Variable

(0 : Existence of Clothoid in Ending of Curve

1 : No Existence of Clothoid in Ending of Curve)

### 4.6 Model Statistics

Table 6 summarizes the model statistics.

Table 6 Model Statistics

| | Confidence Level | R | $R^2$ | Adjust $R^2$ | Standard Error | t-Statistic | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | L | R | CL | RR | $Bend_{Ver.}$ |
| CASE 1 | 95% | 0.764 | 0.584 | 0.567 | 5.795 | 4.273 (0.000) | - | - | - | 2.632 (0.010) |
| CASE 2 | 95% | 0.811 | 0.657 | 0.636 | 5.626 | -6.728 (0.000) | 6.406 (0.000) | -3.952 (0.001) | - | 15.406 (0.000) |
| CASE 3 | 95% | 0.846 | 0.715 | 0.681 | 7.438 | -5.326 (0.000) | - | 5.723 (0.000) | 2.304 (0.015) | 5.662 (0.000) |
| CASE 4 | 95% | 0.838 | 0.703 | 0.675 | 7.245 | -2.740 (0.010) | - | 6.664 (0.000) | 5.906 (0.000) | 8.236 (0.000) |

It was found that the developed models based on classified highway curve types provided significantly higher correlation coefficients with 0.764~0.846. This indicates a high level of relation among included variables. Interestingly different from the normal cases of crash models that have very low determination coefficient values, this research provided models with 0.584~0.715, values rarely observed in crash analysis literature. Therefore, it is believed that this research approach was very effective in explaining crash occurrences for selected freeways. Table 7 is the analysis of variance for the developed models, and also supports the authors' conclusion.

Table 7 Analysis of Variances of Developed Models

| | | d.f | Sum of Squares | Mean Squares | F | Sig. F |
|---|---|---|---|---|---|---|
| CASE 1 | Regression | 2 | 1,771.83 | 885.92 | 33.69 | 0.000 |
| | Residual | 48 | 1,262.33 | 26.30 | | |
| | Total | 50 | 3,034.16 | | | |
| CASE 2 | Regression | 4 | 94,265.32 | 23,566.33 | 549.69 | 0.000 |
| | Residual | 1,148 | 49,216.67 | 42.87 | | |
| | Total | 1,152 | 143,481.99 | | | |
| CASE 3 | Regression | 4 | 4,362.48 | 1,090.62 | 32.65 | 0.000 |
| | Residual | 52 | 1,736.92 | 33.40 | | |
| | Total | 56 | 6,099.40 | | | |
| CASE 4 | Regression | 4 | 37,042.66 | 9,260.67 | 169.19 | 0.000 |
| | Residual | 286 | 15,654.03 | 54.73 | | |
| | Total | 290 | 52,696.69 | | | |

## 5. FINDINGS AND CONCLUSION

This research underscores the importance of applying the consistency concept in geometric design, and applied this concept to freeway crash analysis based on a set of highway curve patterns. The patterns were developed by capturing the crash occurrence characteristics of each different curve types. As a result, the followings were found in this research.

- Longer than 2.4km tangent sections were found to be unsafe.
- Single curve Sections should be designed with longer radii and longer lengths to reduce crashes.
- Compound curve section and reverse curve section involved reduced crashes when two consecutive curves have little curve radius changes, and also showed crash reductions with longer tangent sections between them.
- Fewer crashes were observed when vertical grade values were small, and particularly so if the changes from adjacent sections were minimal.

This research finding should be informative to engineers, and it is expected that this research approach would offer more accurate crash predictions than other existing approaches.

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